NASA CR 102456

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TR-796-9-597

12 AUGUST 1969

# LAUNCH VEHICLE TRAJECTORY OPTIMIZATION COMPUTER PROGRAM - PHASE IV

SUMMARY REPORT

PREPARED FOR:

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
GEORGE C. MARSHALL SPACE FLIGHT CENTER

UNDER CONTRACT NAS8-30509

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By

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# FOREWORD

The Automatic Performance Trade-off Computer program (APT) described herein was designed, coded, and debugged while Northrop was under a fixed price contract (NAS8-30509) to MSFC. The Contracting Officer's Representative throughout the study has been Mr. Bill Goldsby of the Flight Mechanics Branch, Program Development Directorate.

The authors would like to acknowledge Mr. Goldsby and the members of his staff for their helpful support in providing performance data and for their technical contributions to the design of the program.

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# Section I

## INTRODUCTION

The need for quick response by mission planners and the large amounts of optimum performance data that have been generated for a number of launch vehicles of interest has resulted in the NASA request (RFQ DCN 1-7-21-0002) for a quick retrieval system for surveying optimum performance variations due to mission and vehicle variations. Described in this summary technical report is the Automatic Performance Trade-off (APT) computer program which is Northrop's response (under NAS8-30509) to the NASA need. To satisfy the needs of mission planners such a system should have the following characteristics. First, it should efficiently catalog and store information from optimum launch vehicle trajectories in large data banks. Secondly, it should be able to quickly retrieve these data and by using numerical techniques expand its range of usefulness. Finally, it should display these data in several formats each of which have been designed to maximize the immediate usefulness of the data to a particular mission planning function. The Northrop Automatic Performance Trade-off program completely satisfies these requirements.

The benefits to the mission planners from such a system are many fold:

- The efficient utilization of the APT program will tend to eliminate wasteful duplication in the generation of performance data in connection with mission planning activities. Thus, the cataloging and storage system formally gives a permanent "home" to any generated data. This will eliminate the necessity of running most performance variation prediction cases because sufficiently accurate data for all reasonable data points can be found by interpolation and extrapolation of existing numbers in the storage bank.
- Because of the generality of the numerical techniques, data trends, and program logic; newly evolving launch vehicles can be conveniently added to the storage banks by running a minimum number of selected optimum trajectories for data points.
- The program can be asked to display the extent and limitations of its data with respect to any or all of the launch vehicles and a figure of merit is available for all extrapolated payload numbers.
- In addition, if, (1) data points exist for the vehicles of interest, and (2) all vehicle and mission variations are reasonable; then, all mission planners associated with a given study can be immediately provided with new performance data - in a format streamlined for their

immediate needs - whenever study ground rules change. It is believed that this quick response will be of major importance in many studies and allow planners to concentrate on more subtle aspects of the study.

# Section II

# OBJECTIVES

## 2.1 SCOPE OF WORK

The scope of work as stated in the Contract (NAS8-30509) was to devise a computerized technique by which stored data generated from a sophisticated launch vehicle trajectory optimization program can be speedily transformed into meaningful information about specific parameters and vehicle characteristics for immediate use by mission analysts.

## 2.2 STUDY OBJECTIVES

The objectives of the study as stated in the Contract (NAS8-30509) were:

- To develop a data retrieval system in which stored launch vehicle performance data can be quickly transformed into meaningful information for mission planners
- To generate new data by interpolating/or extrapolating within the data bank
- To develop a cataloging procedure for the various missions for storing performance information.

The Automatic Performance Trade-off (APT) computer program described in this document completely satisfies the objectives of the contract. This program is capable of storing data so that variations in vehicle performance can be studied as a function of both mission and vehicle parameters. This program contains a multi-dimensional interpolation routine which can handle up to four independent variables. The data banks used in the program are a result of the cataloging techniques developed during this study. This program will be a useful tool for the mission planners and give them a quick response capability for preliminary mission planning.

## 2.3 MISSIONS

As previously mentioned, the objective of the program is to account for performance variations in launch vehicles due to variations in both mission parameters (launch azimuth, orbital altitude, and ascent profile) and vehicle parameters (thrust, ISP, and stage weight). These variations were to be cataloged for the following missions.

- Low Earth Orbits
- Polar Orbits
- High Energy Missions
- Synchronous Orbits.

The low earth orbits, both circular and elliptical, are defined to be those orbits whose altitudes range from 100 to 500 n mi. These orbits are achieved by direct injection with no yaw steering.

Polar orbits, both circular and elliptical, are achieved by using a yaw steering maneuver. This yaw maneuver starts at some time, t, after lift-off and continues at a constant rate until the desired polar orbit is achieved. The yaw rate used was that rate which resulted in obtaining the maximum payload in the final orbit. The two launch azimuths used with this problem were 45 and 145 degrees.

High energy missions are those where twice the energy per unit mass has been specified. These missions proceed first to a 100 n mi circular parking orbit. Then the engines are reignited and burn until the desired energy level is achieved. The high energy missions considered by the program assumed that no plane change is required.

Earth equatoral synchronous orbits are achieved by first injecting into a 100 n mi circular parking orbit. The vehicle then performs a 2.5-degree plane change maneuver leaving parking orbit and removing the remaining inclination at apogee. The path from the parking orbit to the final orbit is assumed to be that specified by a Hohmann transfer.

Also considered were inclined orbits with sychronous orbit altitudes. These orbits were achieved similarly to those of earth equatorial orbits but without any plane change.

An additional service was supplied with the synchronous orbit problem. The program will determine launch azimuth opportunities so that the vehicle leaving park orbit (departure from the ascending or descending node) will inject into the final orbit over some specified longitude.

For the above mission, due to range safety requirements, only the launch azimuth spectrum from 45 to 145 degrees is considered. The program is also capable of reproducing a stage impact trace for the above mission as a function of mission parameters.

# Section III

# RESULTS

The principal results of the study were the design, construction, and debugging of the Automatic Performance Prediction (APT) computer program. The successful development of the program satisfies the study objectives given in subsection 1.2 in every respect.

## 3.1 PERFORMANCE VARIATIONS FOR VARIATIONS IN MISSION PARAMETERS

From the study, cataloging techniques were developed for storing performance effects as a function of mission parameters for the various missions. The cataloging techniques resulted in storing a minimum number of points and at the same time maintain the integrity of the interpolated results. The spacing of the data points for the various missions was determined such that the error induced by interpolation would be negligible. The program determines a figure of merit which is an estimate of the error which results when extrapolating beyond a data bank for a payload. This figure of merit is printed only when the estimate is greater than 2 percent.

## 3.2 PERFORMANCE VARIATIONS FOR VARIATIONS IN VEHICLE PARAMETERS

The effects of performance variations due to changes in any of the vehicle parameters are predicted by the use of psuedo-partial derivatives of payload with respect to each vehicle parameter. These psuedo-partial derivatives are called exchange ratios. Care must be taken in using these exchange ratios to insure that the range over which they can be assumed linear is not exceeded.

## 3.3 STAGE IMPACT TRACE

Sufficient data can be stored in the program to generate stage impact traces for the various missions. The program will only handle impact traces as a function of mission parameters. A simple scheme was found for handling impact traces as a function of launch azimuth for all mission except for polar orbits. These orbit were handled differently because a yaw steering maneuver had to be accounted for. The impact traces for the high energy missions and the synchronous orbits are to the 100 n mi circular parking orbit for any azimuth.

## 3.4 DATA STORAGE

The performance information mentioned previously is stored in large data banks. The data is stored in BLOCK DATA routines which are linked to the main program. Each BLOCK DATA routine contains all the information stored for a particular vehicle. By storing data in this form instead of on tape, it was not necessary to develop routines for the program which could read and write on tapes. These data banks in BLOCK DATA form are easily accessable for modifications and additions to the data. New data banks for new vehicles can easily be added to the program as they become available.

## 3.5 INTERPOLATION/EXTRAPOLATION METHOD

The Lagrange method of interpolation was selected for use in the program. One of the major reasons for selecting this method was that it does not require equal spacing between consecutive values of the independent variable. This method was easily programmed and extended to handle several independent variables. The value of the dependent variable obtained from multi-dimensional interpolation, based on Lagrange's method, is independent of which independent variable is interpolated for first.

## Section IV

## CONCLUSIONS

The study has shown that a system could be developed where performance information obtained from sophisticated launch vehicle optimization programs can be stored and retrieved without loss of integrity in the data. Numerical techniques can be used to interpolate and extrapolate to generate new data from these data banks. The program performs equally well in determining both payload information and stage impact traces.

The cataloging techniques have shown that the data can easily be spaced so that the error due to interpolation for payload information can be kept well below one percent. These cataloging techniques developed for the various missions will be extremely useful guidelines in generating data for new vehicles.

The output formats developed for the various missions are in report form. This will leave the analyst free to persue more important tasks.

The data retrieval system developed by Northrop, with the above features, will be a very useful tool to mission planners. It provides efficient guidelines for generating performance information, provides a place to store this information, and will expand the range of usefulness of the information.

# Section V

# RECOMMENDATIONS

The following recommendations are made for increasing the usefulness of the program to the mission planner. These recommendations, if implemented, will give the planner the capability of faster response to problems from conception to the final report.

- Develop into the program the capability of call sophisticated launch vehicle optimization programs. Thus, when searching for information which lies at a large distance outside the data bank, the optimization programs would be called. Runs could then be made using the optimization decks which would increase the data bank to the appropriate size. The appropriate size would be where the error encountered by interpolation and extrapolation would be acceptable. This information which was generated would then be stored for future use.

  Another use for this feature would be with new vehicles. Here the appropriate vehicle data could be supplied along with the types of missions to be considered. A data spectrum would then be generated for a given mission in accordance with the cataloging technqiues previously defined. This data could then be stored for future use. This option would reduce human error to a minimum. The gain in efficiency would greatly increase the mission planner's response for preliminary studies.

- It is recommended that a conversational mode be added to the program. This feature would allow the user to communicate with the program. It would allow the program to be used by more people by eliminating the time required to study program documentation.

  With a conversational mode the program would proceed in the following manner. Initially, the program would display the program's major options in sequence to the user. The user could select the desired options by input through a typewriter . After selecting the various options, the program would then display the corresponding information stored for the various vehicles. The user then selects the appropriate vehicles. The program, stepwise, shows the user how to input values for the mission and vehicle parameters for which he desires performance information. The program would then determine the desired information by interpolation and extrapolation techniques. The program would then display output options which are available. The process could be repeated until the user has solved his particular problem. This type of mode could also be connected to the data storage banks. Then the user could be given detailed instructions in how to store his data for future use.

- At present, the program only outputs using a standard printer. The incorporation of the use of other types of output devices would enhance the usefulness of the program. The addition of plotting routines could be used to show trends in vehicle performance. They can also be used to show impact trace on a graph of the earth. The use of an oscilloscope output would be helpful in connection with the conversational mode. The output mode would also allow the user to see his results before having them printed.